# DESIGN OF A SPAN STEEL SPANDREL - BRACED TWO - HINGED ARCH.

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DESIGN OF A

# 210' SPAN STEEL SPANDREL-BRACED TWO-HINGED ARCH.

A THESIS

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# The Two-Hinged Spandrel-Braced Steel Arch.

It is customary in the study of arched structures to classify them all under one of three heads, according to the number of hinges they have; therefore, we have the three-hinged arch with two abutment hinges and one at the crown, the two-hinged arch with only the two abutment hinges, the one-hinged arch with a hinge at the crown, and the no-hinged arch having, as the name indicates, no hinges. The last two named types of arches, however, have found but little application in the engineering practice of recent years, and as a consequence have not reached the development attained by the two and three-hinged arches.

The main feature in distinguishing an arched structure from a simple truss or beam is in the matter of reactions. The simple truss under vertical loads has vertical reactions provided one end is so arranged as to permit lateral movement due to deflcetion of truss and to temperature changes; but when the abutments are fixed so as to prevent this lateral movement at the supports, the truss comes under the head of arched structures with reactions which are no longer vertical, being, as they are, in the nature of outward thrusts on the abutments.

In selecting the two-hinged type of arch for study it is necessary to go into a further classification of them, so we divide them into the arch-rib type and the spandrel-braced type. In the former the arch rib alone is subjected to the arch action, the panel loads being applied directly to the rib in such a manner that the part above the rib takes no part in resisting the bending moments and shears.

Another type of the arch rib, also known as a "braced arch", is found in the arch truss consisting of two curved parallel chords connected by diagonal bracing. This style is sometimes confused with the spandrel braced arch of the kind to be described more in detail in the following pages, i. e., the type having a straight horizontal upper chord and an arched lower chord connected by vertical and diagonal bracing. In this arch each and every member of the structure assist in resisting the action of applied loads, at least under most conditions of loading.

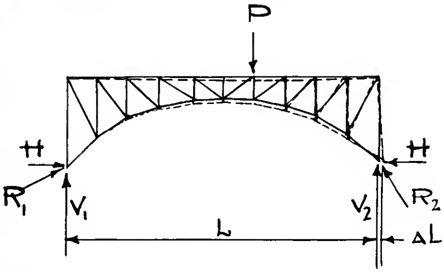
As has been stated the main feature distinguishing the arch from other trussed structures is in the matter of its reactions, which we find may be resolved into vertical and horizontal components - the latter being known as the "horizontal thrust". Thus we find that the arch must be designed to resist stresses due to vertical forces, as in a simple truss, and also to resist stresses due to this horizontal thrust which is caused by deflection of arch and changes in temperature.

In an arch having three hinges this horizontal thrust is easily determined from the simple conditions of static equilibrium. Since the bending moments at the hinges are known to be zero, by taking moments about the center hinge we can write equations in terms of loads and reactions which when equated to zero can be solved for the values of the vertical reactions and horizontal thrust. The two-hinged arch, on the other hand, does not supply a sufficient number of equations of static equilibrium from which to determine these values, so recourse must be had to some other method. This method, as we shall see, is based on either the "elastic theory" or the principle of "least work". The two best known and widely

used application of these two theories are found in methods outlined by Professor Charles E. Greene in his book on "Trusses and Arches, Part III" and in Professors Mansfield Merriman and Henry S. Jacobys' book on "Roofs and Bridges, Part IV". The method as given in Professor Greene's book will be used in the solution of the problem in hand.

Derivation of Formula for the Horizontal Thrust.

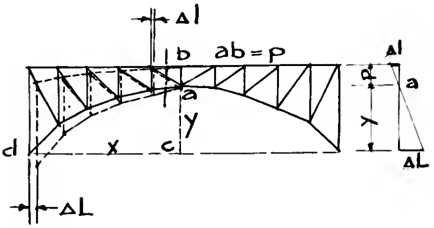
Referring to the sketch given below, first consider the arch fixed at the left abutment but free to move laterally at the right abutment, this condition being indicated by the full lines. Then,




under application of load P, changes in lengths of the members of the arch will be produced, thus causing the arch to deflect and the free hinge to be pushed outward as indicated by the dotted lines.

Now if a horizontal force by applied to this free end and of a magnitude sufficient to cause the arch to resume its original position - as shown in full lines - we will have duplicated the stresses in the arch which would be present under application of load P while the hinges are prevented from spreading. In order to obtain the value of this horizontal force necessary to prevent the spreading of the abutment hinges, we first must get the stresses in the members due to a certain loading and then determine the deformations in the members due to this loading. Having these we are enabled, thru an application of the principle of instantaneous centers to find what would be the deformation or movement of the hinges at abutments. From the elastic deformation method, or application of Hooke's Law,

we obtain the expression, $E = \frac{Tl}{A\Delta l}$ (1) where E is the modulus of elasticity, T the total stress in the member, l the length of the member in inches, A the area of the member, and $\Delta l$ the deformation in the member due to stress T.




In the accompanying diagram let

x = the distance of the center of moments from left abutment as "cd".

Y = the distance of center of moments above springing line of arch, as "ac".

p = lever arm of member, as "ab".

$\Delta L$ = horizontal displacement of arch.

$\Delta l$ = deformation in member.

As previously stated the total horizontal movement of arch at abutments may be considered as made up of the sum of the separate deformations of the members. To consider the effect of change of length in one member to total change of length of arch span, pass a plane cutting three members of arch as shown in above sketch; then draw two of them to an intersection and we get from the principle of instantaneous centers as outlined in any text on Kinematics, the expression $\frac{\Delta L}{\Delta l} = \frac{Y}{p}$ (2) or, to express it in words, the amount of deformation in member is to the total deformation of arch as distance of member from this instant center is from the abutment hinge.

Now let P = vertical force acting upward at abutment

H = horizontal thrust at abutment

t = stress produced in member by H

t' = stress produced in member by P

$T = t + t'$, or total stress in member.

Taking moments about "a", we get,

$$t \times ab = H \times ac \qquad \text{or} \qquad t = \frac{H \times ac}{ab} \qquad (3)$$

$$t' \times ab = P \times cd \qquad \text{or} \qquad t' = \frac{P \times cd}{ab} \qquad (4)$$

Now in order to make equations (3) and (4) more general, substitute for ab, ac, and ad, their equal values p, y, and x, respectively. Then equations (3) and (4) may be written $t = \frac{H.y}{p}$ and $t' = \frac{P.x}{p}$

Also $T = t + t'$ equals $T = \frac{Hy}{p} + \frac{Px}{p}$ or $T = \frac{Hy \quad Px}{p}$ (5)

From (1) $\Delta L = \frac{y}{p} \Delta l$ and from (2) $\Delta l = \frac{TL}{AE}$. $\therefore \Delta L = \frac{y}{p} \cdot \frac{Tl}{AE}$.

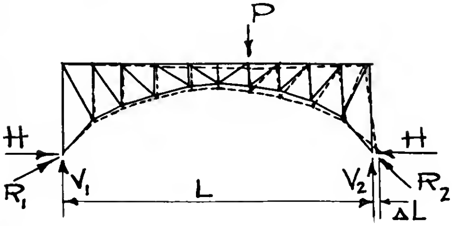
From (5) and (6) $\Delta L = \frac{y}{p} \cdot \frac{1}{AE} \times \frac{Hy + Px}{p} = \frac{1}{AE}\left(\frac{Hy^2}{p^2} + \frac{Pxy}{p^2}\right)$.

Calculating this value of $\Delta L$" for every member of the arch, and adding them together gives for the total horizontal displacement of arch $\Delta L = \frac{1}{AE}\left(\sum \frac{Hy^2}{p^2} + \sum \frac{Pxy}{p^2}\right)$. Since the construction of the arch abutments are such as to prevent this lateral movement or change in length of span, $\Delta L$ must be equated to zero. Therefore, in solving the above equation for H, we get $H = \frac{\sum P \frac{xy}{p^2}\frac{1}{AE}}{\sum \frac{y^2}{p^2} \cdot \frac{1}{AE}}$ (6)

This then is the general formula for determining the horizontal thrust "H", and is applicable to any spandrel-braced arch. We also note that it contains the unknown value "A", the area of the member, so for purposes of preliminary design this will be considered as unity; and since the term $\frac{1}{AE}$ appears in both numerator and denominator of above expression it may be omitted in the preliminary design. Accordingly, the formula to be used for determining the value of the horizontal thrust due to a load at each successive panel point may

be written $$H = \frac{\sum \frac{Pxyl}{p^2}}{\sum \frac{y^2 l}{p^2}}.$$

The method of determining the horizontal thrust as outlined in the book by Professors Merriman and Jacoby involves in addition to the elastic theory the principle of least work, or the internal work in the members counteracting the work of external forces.




Considering the arch fixed at the left end but free to move laterally at the right, it may, under no load, be represented as shown in full lines in accompanying sketch. Upon the application of a vertical load P, however, it will assume the position indicated by the dotted lines, the right hinge moving outward a distance $\Delta L$. Now if we apply a horizontal force H of sufficient magnitude to bring the arch back to its original position (shown in full lines) we will have placed the arch in identically the position and under the same conditions existing in a two-hinged spandrel-braced arch under action of vertical load or loads. In order to deduce an expression for the value of this displacement $\Delta L$, were the arch free to move laterally, let

P = vertical load on arch

L = length of member in inches

A = area of cross section of member

S'= stress produced in member by vertical load P

T = stress produced in member by horizontal force of unity applied at the abutment.

e = change in length of any member due to force of unity acting horizontally at the abutment.

$\Delta$ = total displacement of arch.

Now from Hooke's Law we know that $e = \frac{TL}{AE}$, and the internal work in the member will be equal to $\frac{1}{2}S'e = \frac{\frac{1}{2}S'TL}{AE}$. Hence, for the entire arch the total internal work is $\sum\frac{\frac{1}{2}S'TL}{AE}$. The external work done by this horizontal force of unity acting through the displacement of the arch is equal to $\frac{1}{2}(\Delta.1)$.

Equating these two values of work, the formula reduces to

$$\Delta = \sum\frac{S'TL}{AE} \qquad (8)$$

Now, if we let U be the stress in any member of the arch due to the horizontal thrust H, we will have that $U = H.t.$ Considering e' the deformation on member under stress U, we find that the internal work in member is $\frac{1}{2}Ue'$. But, $e' = \frac{UL}{AE}$. $\therefore \frac{1}{2}Ue' = \frac{\frac{1}{2}U^2L}{AE}$

Equating this to the external work,

$$\frac{1}{2}(H\Delta) = \frac{\frac{1}{2}U^2L}{AE} \quad \text{or for complete arch} \quad \Delta = \frac{1}{H}\sum\frac{U^2L}{AE}$$

Substituting HT for U, formula for $\Delta$ reduces to $H\sum\frac{T^2L}{AE}$. (9)

Equating formulae (8) and (9), we get the expression $H = \frac{\sum\frac{S'TL}{AE}}{\sum\frac{T^2L}{AE}}$ from which may be computed the horizontal thrust for any trussed two-hinged arch due to a load P. It is also to be noticed that this is an expression for getting the value of H under any system of loading, providing S' represents the stresses due to that loading. The stresses S' are always calculated from the vertical reactions $V_1$ and $V_2$, the same as if the arch were a simple truss. For purposes of a preliminary design the value of A in the above formula is taken as unity. For the sake of comparison it is interesting to note that the formula by Greene for $H = \frac{\sum\frac{Pxy\,l}{p^2AE}}{\sum\frac{y^2\,l}{p^2AE}}$ may be changed very easily to the form above given by merely substituting for T its equivalent $\frac{Hy}{p}\frac{Px}{p} = \frac{H\sum\frac{Pxy}{p^2}}{H^2\sum\frac{y^2}{p^2}}$ the H dropping out, since value of T is derived by taking H as unity.

The Design.

Among the number of modern steel structures that span the deep gorges and ravines on the Guatemaula Railroad is a three-hinged spandrel-braced steel arch of about 210' span, crossing what is termed the Rio Fiscal. Since the geological formation at this point was found to be ideal for the construction of a two-hinged arch, this site was selected for the arch to be designed according to methods as already outlined. The present structure at this point is a single-track, 3'-6" gauge, deck arch-bridge having provision made for widening to standard gauge at some future date, and is calculated to withstand the stresses resulting from the passage of two 73½ ton Mogul type engines followed by a uniform load of 5000# per foot of bridge.

This same loading was used in our design of a two-hinged arch for this place, it being found that the locomotive gave an excess panel load of 35,000# followed by a live load per panel of 27,000#. From several existing arches of approximately the same span as the one chosen, the dead load per panel was estimated as 20,000#, and final calculations confirmed us in this estimate, the final average dead panel load being 19,000#. In design of arch members the American Railway & Maintenance of Way Association's specifications for railway bridges were used, and for purpose of comparison checked by Cooper's specifications for railway bridges, the two being found to vary but slightly in final results. On plate #1 are to be found all of the data used in the design of the arch as hereinafter given.

The first step in the determination of the horizontal thrust from the formula $H = \dfrac{\sum P\frac{xyl}{AE}}{\sum \frac{y^2 l}{AE}}$ was to obtain the values of x/p and y/p,

this being accomplished by means of the diagrams shown on plates #2 and #3 and tabulations on plate #4. By multiplying these values of x/p and y/p with "l" we obtain the values of xyl/p, a summation of which is in the numerator of formula (6), this being shown on plate #5. Similarly a summation of values of y l/p, the denominator in formula (6) is tabulated on plate #6.

The next procedure was to obtain the preliminary value of H for a load P on each panel point: results so obtained are tabulated on plate #7. Knowing the values of the vertical reactions and horizontal thrusts for a load at each panel point, a determination of, the stresses in the arch members under panel loads of 1,000# was accomplished by the graphical methods illustrated in the diagrams on plates #16, to #20, inclusive, and results on plate #8. Since the dead, live, and excess panel loads were 20,000#, 27,000#, and 35,000#, respectively, it was merely a matter of multiplying the above mentioned stressed by 20, 27, and 35, to obtain the actual stresses in the members under the preliminary values of V and H. The results of this calculation are given on plates #9, #10, and #13.

Owing to the condition that the arch is anchored at the abutments only, while the greater part which is exposed to the action of lateral and wind forces is at a considerable distance above the anchorage, large overturning moments are given rise to, thus producing vertical forces acting downward on one side of the arch and upward on the other, the transfer of these forces taking place through the sway bracing. We find that the distribution of the wind and lateral forces in a two-hinged arch is not strictly determinate, but after a little consideration of the subject we should expect to find the most rigid members taking these stresses; hence,

we calculated that the upper lateral system, with its heavy floor-beams connections and heavy chord members, would carry all of the wind and lateral forces on the upper chord to the end portal and thence to the abutment, thus leaving the lower lateral system to carry to the abutment only the wind loads on the lower part of the arch. In the design of the sway bracing, however, all of the lateral forces on the upper chord were considered as coming down to the lower chord. All wind and lateral forces were considered to act as live loads.

Since the lower chord panel points are not in the same horizontal plane, we find that a load (horizontal) at each panel point produces an overturning moment about the next lower panel point toward the abutment. These overturning couples, however, may be resolved into vertical loads on the arch, thus causing additional stresses in the arch members. The stresses so obtained are shown in table #11.

The design of the upper and lower lateral systems and of sway and portal bracing were accomplished analytically and stresses found are tabulated on plates #26 and #27. On plate #27 are also given the results obtained in the analytical design of the floorbeams and stringers.

Before a final summation of the various stresses could be made, it was necessary in accordance with the specifications to take into account impact stresses, these to be calculated according to the formula, Impact $= \frac{S \cdot 300}{300 + L}$, where S is the live load stress in the member, and L the loaded length of the arch causing this maximum live load stress. These results are given in the table on plate #13.

The preliminary temperature stresses were calculated according to the method given in Higher Structures, Part IV, a method based again on the elastic theory. By means of the displacement diagram, so called because it gives the relative displacements and final positions of the various panel points due to deformations in the stressed members of the arch when all points - except the middle member - are considered free to move, we found that under a rise or fall of temperature of 50 degrees Fahr. the abutment hinges would be thrust outward a distance of 239", assuming for ease of calculation an area of unity for each of the members and an value of 10,000 pounds for the coefficient of elasticity E, and stresses in members those due to a horizontal thrust of 100#. This horizontal thrust can be used in the calculation of the temperature stresses, because it is well known that the effect of changes in temperature on a two-hinged arch is to produce stresses in arch members the same as those caused by a horizontal force applied at abutment hinges. A reduced figure of this displacement diagram is shown on plate #12, the short heavy lines denoting th deformations in members and the light lines the direction of movement and final location of the various panel points with regard to the fixed member LL'. The Actual movement of the hinges, were they free to move laterally, under a rise or fall of temperature of 50 degrees, we found to be 210' x 12" x 50 x .0000065 = .819". Now taking the deformation of 239" obtained under the assumption that E is 10,000 and A unity, we divide it by 3,000 x 26.5, the last figure being the assumed average areas of the members. This gives .0015" total movement of abutment hinges under a horizontal load of 100#. Dividing the amount of movement of hinges occasioned by temperature changes by this value

gives 27,300# as the amount of horizontal thrust required to counteract the effect of temperature changes. Multiplying the constants given in table #14 by this value of H gives the stresses in the arch members due to this cause.

In determining the final temperature stresses a final displacement diagram as shown on plate #12 was constructed. The deformations used in the construction of this diagram were calculated from the usual formula, but using actual areas in place of assumed areas. The final value of horizontal thrust due to temperature was found to be 17,850#, and the final stresses as tabulated on plate #24 and #25.

With all of the preliminary stresses determined, as shown on plate #13, we proceeded with the design of the arch members. In determining these preliminary areas, as well as the final areas, the wind stresses were not taken into consideration unless they amounted to 30% of the sum of the stresses from all other sources. Where they did amount to 30% of the sum of the other stresses, the designing stress was increased 25% over what ordinarily would be allowed, this being as per specifications. The web tension members were designed under an allowable stress of 16,000# per square inch, and members in compression according to the straight line formula $S \quad 16{,}000\# - 70\frac{l}{R}$ . Where members were found to undergo a reversal of stress during the passage of a train over the structure, 50% of the smaller stress was added to the larger and member designed in keeping with this result.

After having determined our preliminary values of the areas of the members, we proceeded to determine a more accurate value of the horizontal thrusts from loads on the different panel points. It

will be remembered that in obtaining the preliminary values of H, we treated the value of A in the equation $H=\frac{\sum \frac{Pxyl}{p^2AE}}{\sum \frac{y^2 l}{p^2AE}}$ as unity, Now going back and placing these preliminary values of A in these equations, new values of the horizontal thrusts were obtained as shown on plates #14 and #15. An inspection of the preliminary and last named values of H obtained show that there is but little difference, so little difference in fact that it was not considered necessary to make a third calculation for it.

With these new values of H given on plate #15 the same procedure as has just been outlined was followed, preliminary diagrams corrected in their values of H and new diagrams drawn, from which were scaled the true stresses in the members. The diagrams on plates #16, #17, #18, #19, and #20 show the stresses in the arch members due to loads of 1,000# on panel points 1, 2, 3, 4, and 5, respectively. These values are tabulated on plate #21, and the summation column gives the stresses in members due to a dead panel load of 1,000# on each panel point. The actual dead load stresses, obtained by multiplying the values in the summation column of plate #21 by twenty, are tabulated on plate #24.

As in the preliminary, the values of the live load stresses due to a panel load of 27,000# are obtained by multiplying the constants in table #21 by twenty-seven. These results are tabulated on plate #22, and stresses due to excess panel load of 35,000# are given on plate #23. In determining the maximum stress in a member we placed the excess panel load at the panel point giving the greatest stress in the member, and considered the remaining panel points, causing the same kind of stress, covered with a live load of 27,000#.

The final stresses caused by combination of live, dead, wind, temperature, and impact loads are tabulated on plate #24, and a summary of all stresses together with final design, size, and weights of members are given on plate #25.

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[illegible]

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| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |

# Preliminary [illegible]

[illegible]

Stresses due to a Single [illegible]
at panel points as [illegible]
considered [illegible]

| Mem. | Joint [illegible] | #2 | #3 | #4 | [illegible] |
|---|---|---|---|---|---|
| BD | -393 | -249 | -133 | [illegible] | [illegible] |
| BF | -569 | -726 | -454 | [illegible] | [illegible] |
| BH | -315 | -646 | -1072 | [illegible] | [illegible] |
| BJ | -194 | -441 | -888 | [illegible] | [illegible] |
| BL | -48 | -169 | -434 | [illegible] | [illegible] |
| | | | | | |
| AC | -300 | -577 | [illegible] | [illegible] | [illegible] |
| AE | +157 | -119 | -565 | [illegible] | [illegible] |
| AG | +127 | +79 | -721 | [illegible] | [illegible] |
| AI | +66 | [illegible] | +419 | [illegible] | [illegible] |
| AK | -57 | [illegible] | +145 | +46[illegible] | [illegible] |
| | | | | | |
| BC | -794 | -469 | [illegible] | [illegible] | [illegible] |
| DF | -97 | -339 | -410 | [illegible] | [illegible] |
| FG | +56 | -930 | [illegible] | [illegible] | [illegible] |
| HI | +85 | +163 | -769 | [illegible] | [illegible] |
| JK | +105 | -207 | -163 | [illegible] | [illegible] |
| | | | | | |
| CD | +880 | [illegible] | [illegible] | +75 | [illegible] |
| EF | -36 | +650 | +540 | +173 | +65 |
| GH | -78 | -140 | +830 | +555 | +165 |
| IJ | -149 | -76 | -340 | +356 | [illegible] |
| KL | -179 | -345 | +49[illegible] | [illegible] | [illegible] |

Preliminary Live [illegible]
due to Excess Panel [illegible]

| Member | [illegible] | [illegible] | [illegible] |
| --- | --- | --- | --- |
| BD | [illegible] | [illegible] | [illegible] |
| BE | [illegible] | [illegible] | [illegible] |
| BH | [illegible] | [illegible] | [illegible] |
| BJ | [illegible] | [illegible] | [illegible] |
| BL | [illegible] | [illegible] | [illegible] |
| | | | |
| AC | [illegible] | -20195 | [illegible] |
| AE | [illegible] | [illegible] | [illegible] |
| AG | [illegible] | -10185 | [illegible] |
| AI | [illegible] | [illegible] | [illegible] |
| AK | [illegible] | [illegible] | [illegible] |
| | | | |
| BC | [illegible] | [illegible] | [illegible] |
| DE | [illegible] | [illegible] | [illegible] |
| FG | [illegible] | [illegible] | [illegible] |
| HI | [illegible] | [illegible] | [illegible] |
| JK | [illegible] | [illegible] | [illegible] |
| | | | |
| CD | [illegible] | [illegible] | [illegible] |
| EF | [illegible] | [illegible] | [illegible] |
| GH | -2730 | [illegible] | [illegible] |
| IJ | -5220 | [illegible] | [illegible] |
| KL | -6270 | -12100 | [illegible] |

[illegible]

[illegible]

KL. [illegible]

Wind Stresses in Arch Mem[illegible]

Loads resulting from [illegible]

L[illegible]

| Member | Joint #1 | #2 | [illegible] |
|---|---|---|---|
| Load | 26[illegible]0 | 17[illegible] | [illegible] |
| BD | +10[illegible]50 | -43[illegible] | [illegible] |
| BF | +96[illegible] | -129[illegible] | [illegible] |
| BH | [illegible] | [illegible] | [illegible] |
| BJ | [illegible] | [illegible] | [illegible] |
| BL | [illegible] | [illegible] | [illegible] |
| | | | |
| AC | -78[illegible] | [illegible] | [illegible] |
| AE | +41[illegible] | [illegible] | [illegible] |
| AG | [illegible] | [illegible] | [illegible] |
| AI | [illegible] | [illegible] | [illegible] |
| AK | [illegible] | [illegible] | [illegible] |
| | | | |
| BC | -191[illegible] | [illegible] | [illegible] |
| DE | -25[illegible] | [illegible] | [illegible] |
| FG | [illegible] | [illegible] | [illegible] |
| HI | [illegible] | [illegible] | [illegible] |
| JK | [illegible] | [illegible] | [illegible] |
| | | | |
| CD | [illegible] | [illegible] | [illegible] |
| EF | -93[illegible] | [illegible] | [illegible] |
| GH | -2085 | [illegible] | [illegible] |
| IJ | -3893 | [illegible] | [illegible] |
| KL | -46[illegible] | -6[illegible] | [illegible] |

Preliminary [illegible]
Arrangement [illegible]
calculated [illegible]
due to the [illegible]
E = 10000.

| | |
|---|---|
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| H[illegible] | [illegible] |
| [illegible] | [illegible] |
| [illegible] | [illegible] |
| EF | [illegible] |
| GH | [illegible] |
| IJ | [illegible] |
| KL | [illegible] |

[illegible] [illegible]

[illegible]

Stress [illegible]

[illegible]

Final Stresses [illegible]
1000# at each panel point [illegible]

| Mem | [illegible] | [illegible] | [illegible] |
|---|---|---|---|
| BD | - 366 | [illegible] | [illegible] |
| BF | - 360 | [illegible] | [illegible] |
| BH | [illegible] | [illegible] | [illegible] |
| BJ | [illegible] | [illegible] | [illegible] |
| BL | - 14 | [illegible] | [illegible] |
| | | | |
| AC | - 316 | [illegible] | [illegible] |
| AE | - 189 | [illegible] | [illegible] |
| AG | + 101 | [illegible] | [illegible] |
| AI | + 96 | [illegible] | [illegible] |
| AK | + 97 | [illegible] | [illegible] |
| | | | |
| BC | + 715 | [illegible] | [illegible] |
| DE | - 933 | [illegible] | [illegible] |
| FG | + 64 | - 886 | [illegible] |
| HI | + 93 | - 172 | [illegible] |
| JK | + 108 | [illegible] | [illegible] |
| | | | |
| CD | + 873 | [illegible] | [illegible] |
| EF | - 46 | + 68 | [illegible] |
| GH | - 89 | - 159 | [illegible] |
| IJ | - 161 | - 277 | [illegible] |
| KL | - 185 | - 357 | [illegible] |

Fi[illegible] Live Loa[illegible]

[illegible]

| Member | Total | [illegible] |
|---|---|---|
| BD | [illegible] | [illegible] |
| BF | [illegible] | [illegible] |
| BH | [illegible] | [illegible] |
| BJ | [illegible] | [illegible] |
| BL | [illegible] | [illegible] |
| | | |
| AC | [illegible] | [illegible] |
| AE | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] |
| AK | [illegible] | [illegible] |
| | | |
| [illegible] | [illegible] | [illegible] |
| DE | [illegible] | [illegible] |
| FG | [illegible] | [illegible] |
| HI | [illegible] | [illegible] |
| JK | [illegible] | [illegible] |
| | | |
| CD | [illegible] | [illegible] |
| EF | [illegible] | [illegible] |
| GH | [illegible] | [illegible] |
| IJ | [illegible] | [illegible] |
| KL | [illegible] | [illegible] |

| Meth[illegible] | |
|---|---|
| BD | [illegible] |
| BF | [illegible] |
| BH | [illegible] |
| BJ | [illegible] |
| BL | [illegible] |
| | |
| BC | [illegible] |
| BE | [illegible] |
| BG | [illegible] |
| BI | [illegible] |
| BK | [illegible] |
| | |
| BC | [illegible] |
| DE | [illegible] |
| FG | [illegible] |
| HI | [illegible] |
| JK | [illegible] |
| | |
| CD | [illegible] |
| EF | [illegible] |
| GH | [illegible] |
| IJ | = 5640 = [illegible] |
| KL | = 6470 = [illegible] |

## F[illegible] Stresses [illegible]

| Member | Dead | [illegible] Live | Live | [illegible] |
|---|---|---|---|---|
| BD | + 9140 | [illegible] | 24197 | [illegible] |
| BF | +23080 | [illegible] | [illegible] | [illegible] |
| BH | +40700 | [illegible] | [illegible] | [illegible] |
| BJ | +59550 | [illegible] | [illegible] | [illegible] |
| BL | -70760 | [illegible] | [illegible] | [illegible] |
| | | | | |
| AC | [illegible] | [illegible] | [illegible] | [illegible] |
| AE | [illegible] | [illegible] | [illegible] | [illegible] |
| AG | [illegible] | [illegible] | [illegible] | [illegible] |
| AI | [illegible] | [illegible] | [illegible] | [illegible] |
| AK | [illegible] | [illegible] | [illegible] | [illegible] |
| | | | | |
| BC | [illegible] | [illegible] | [illegible] | [illegible] |
| DE | [illegible] | [illegible] | [illegible] | [illegible] |
| FG | [illegible] | [illegible] | [illegible] | [illegible] |
| HI | [illegible] | [illegible] | [illegible] | [illegible] |
| JK | [illegible] | [illegible] | [illegible] | [illegible] |
| | | | | |
| CD | [illegible] | [illegible] | [illegible] | [illegible] |
| EF | [illegible] | [illegible] | [illegible] | [illegible] |
| GH | [illegible] | [illegible] | 10297 | [illegible] |
| IJ | +23240 | [illegible] | 2491[illegible] | [illegible] |
| KL | +10420 | [illegible] | [illegible] | [illegible] |

# Summary of Stresses, Sections, & Weights of Members.

| Member | DEAD Pro... Load | LIVE Pos. | LIVE Neg. | TEMP. | TEMP. | MAX. | [illegible] | SECTIONS | Area | WEIGHTS |
|---|---|---|---|---|---|---|---|---|---|---|
| BD | -9140 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 8.87 | [illegible] |
| BF | -23080 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| BH | -40700 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| BJ | -52530 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| BL | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AC | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AE | -112780 | [illegible] | [illegible] | [illegible] | 27150 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AG | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AI | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AK | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

Des

Total s

Use 4-5x

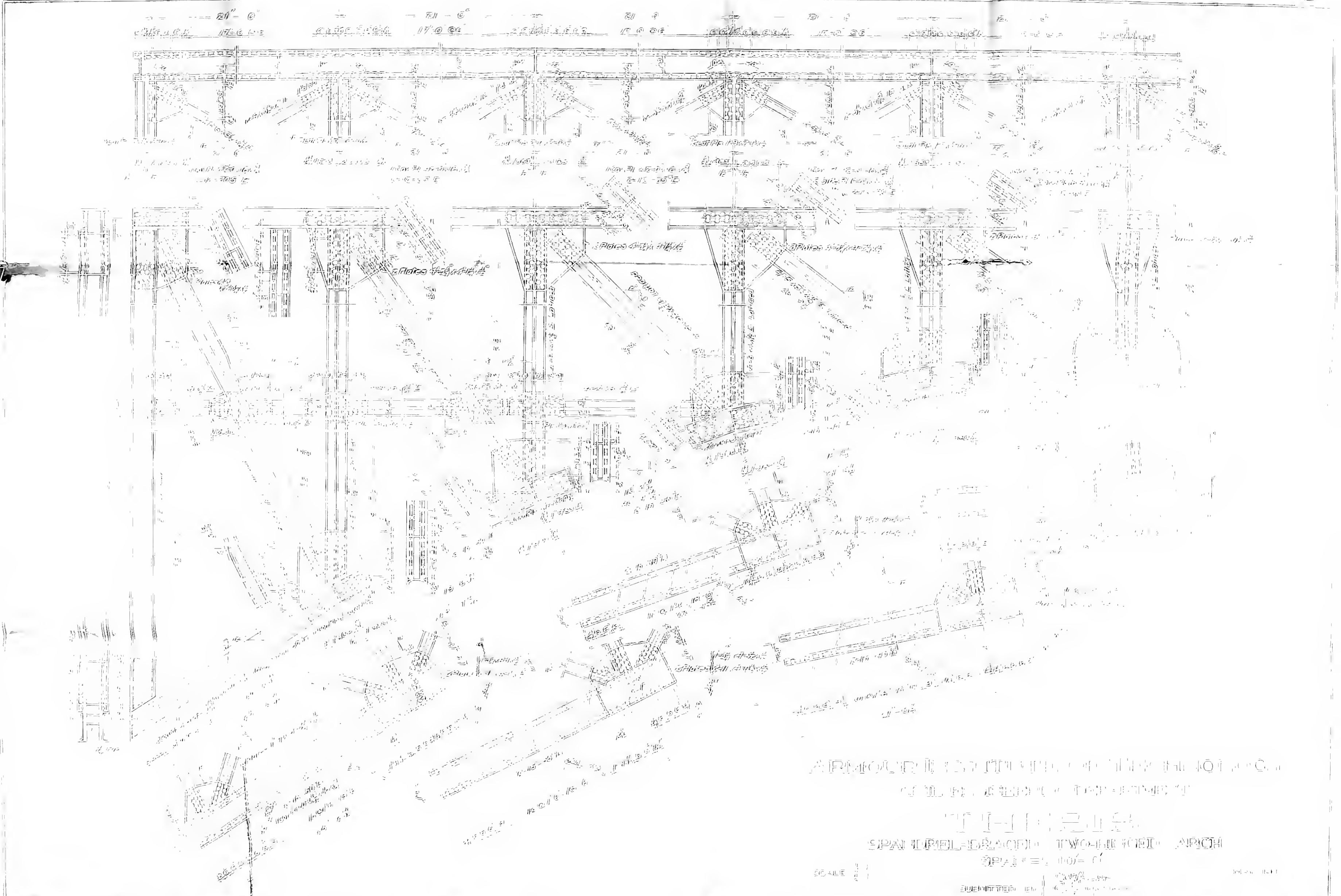
## Design of Stringers

Span = 21 ... Stringers ...

Dead Load ...

Max. ...

Max. M = [illegible] ...



ARMOUR INSTITUTE OF TECHNOLOGY

CIVIL ENGINEERING DEPARTMENT

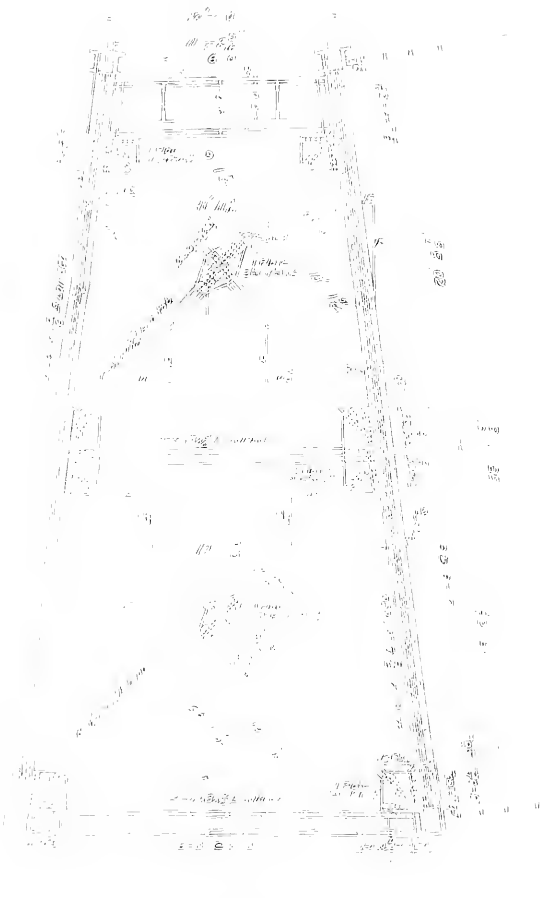
THESIS

SPANDREL-BRACED TWO-HINGED ARCH

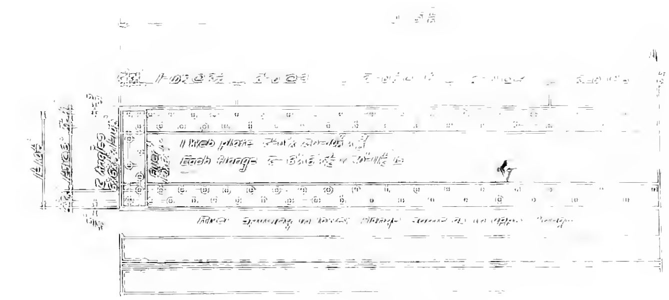
SPAN = [illegible]'-0"

SCALE [illegible]

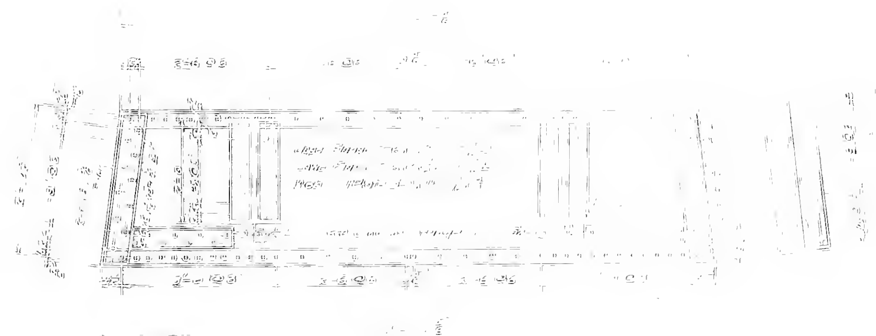
SUBMITTED BY [illegible]



Cross Section at First Panel Point



Stringer



Floor Beam

SHEET [illegible]

FLOOR SYSTEM & [illegible] BRACING